Cambridge Judge Business School

Centre for Risk Studies 7th Risk Summit Research Showcase

Helios: Understanding the Economic Risk of Solar Storms

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Risk Studies

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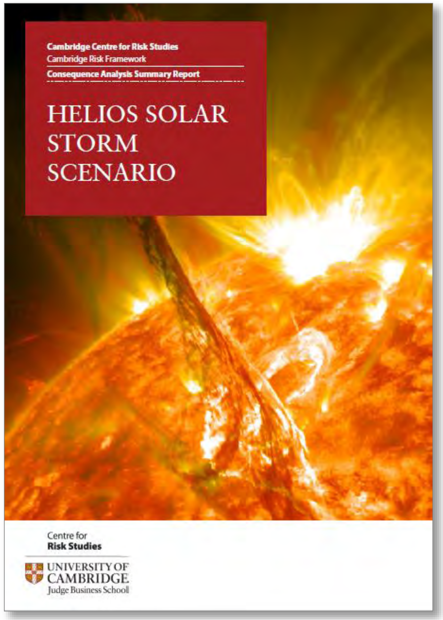
Presentation Outline

- Project information
- What is a solar storm?
- Subject matter experts
- The scenario
- Macroeconomic modelling
- Insurance loss modelling

Helios Solar Storm Project Overview

- Objective: To produce a detailed solar storm scenario with macroeconomic, investment and insurance portfolio impact estimations
- Timeframe: 30 Mar 2015 – 30 Mar 2016
  - Explores the potential economic impact of extreme space weather
  - Develops an open-source risk matrix
  - Undertakes sectoral analysis of global supply chain linkages and total macroeconomic losses
  - Estimates US insurance industry losses

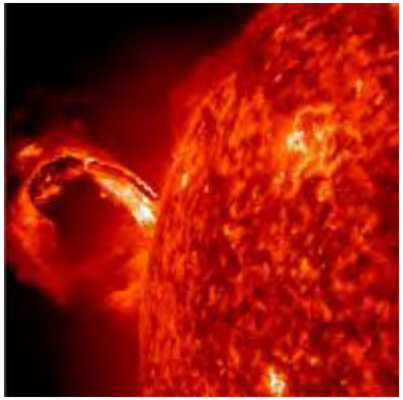


Report to be published in late June 2016

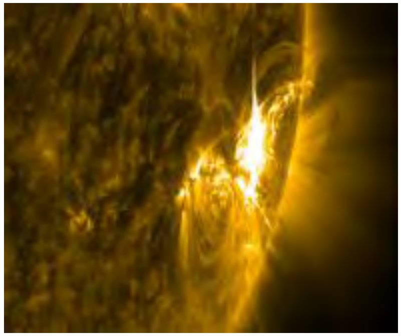
What is a Solar Storm?

- Coronal Mass Ejections (CMEs)
  - A massive burst of gas, matter, magnetic fields and electromagnetic radiation that is released into the solar wind
- X-class solar flares
  - A solar flare is a sudden flash of brightness observed near the Sun's surface
  - Flares can be accompanied by a spectacular coronal mass ejection
- Solar Proton Events (SPEs)
  - When particles emitted by the Sun become accelerated and enter the Earth’s magnetic field
- **An extreme solar storm would feature all three of these phenomena**
- Key Metrics
  - Dst (Disturbance storm time) index, units of nano-Teslas (nT)
  - Rate of change of magnetic fields, units of nT/min
  - There are many other metrics used in physics, maths and other sciences, such as Kp, Ap, G

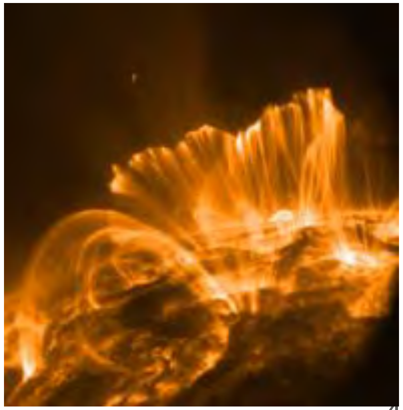
CME



Solar Flare



SPE



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Impacts of Space Weather on Earth

Impact of Space Weather on Earth	Warning Time	Duration	Primary Extreme Event Impact
Radio Blackout	None (speed of light)	Minutes to 3 hours	• Loss of high-frequency (HF) radio communications on Earth's daylight side • Short-lived (minutes to an hour) loss of GPS • Interference on civilian and military radar systems
Radiation Storm	30 minutes to several hours	Hours to days	• Satellite operations impacted. Loss of satellites possible. • HF blackout in Polar Regions. • Increased radiation exposure to passengers and crew in aircraft at high latitudes
Geomagnetic Storm	17 to 90 hours	1 to 2 days	• Possible bulk electricity power grid voltage collapse and damaged to electrical transformers • Interference or loss of satellite and sky wave radio communications due to scintillation • Interference or loss of GPS navigation and timing signals • Satellite operations impacted

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MacAlester, M. H., and W. Murtagh (2014), Extreme Space Weather Impact: An Emergency Management Perspective, Space Weather , 12, doi:10.1002/2014SW001095.

Historical Solar Storm Events

1847
1859 – The Carrington Event caused significant disruption to telegraph systems (Boteler, 2006; Clauer and Siscoe, 2006)
1870
1872
1882 – This storm caused disruption to several US telegraph systems and interrupted trading on the Chicago Stock Market (EIS Council, 2014)
1903
1909
1921 – Similar in size to the Carrington Event, a storm caused fires at several telegraph stations in Sweden (Karsberg et al. 1959)
1938
1940
1958
1989 – It took only 90 seconds for the entire Quebec power grid to collapse and the outage lasted nine hours (Bolduc, 2002)
2000 – The Bastille Day Event saw a very large CME and flare with increased radiation on Earth (Tsurutani et al. 2005)
2003 – The Halloween Storms included a mix of CMEs and flares leading to a one hour power outage in Sweden (Pulkkinen et al. 2005). This storm also led to a radio blackout of high frequency communications, as well as disruption to GPS systems (Bergeot et al. 2010)

Frequency and Severity

- Estimates of the likelihood of geomagnetic storms are not robust because of the short time-series (Hapgood, 2011)
- Riley (2012) suggest that the Carrington event has a 12% probability of occurring every 79 years
- Love et al. (2015) recommend
  - A storm larger than Carrington (-Dst = ≥ 850 nT) occurs about 1.13 times per century:
  - Moreover, a 100-year geomagnetic storm is identified as having a size greater than Carrington (-Dst = ≥ 880 nT)

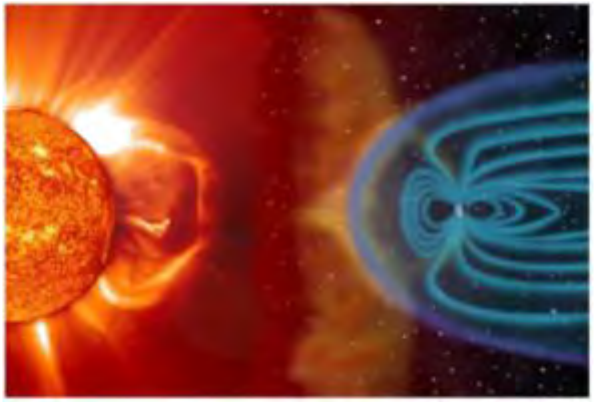
Subject Matter Experts

Scenario Development Workshop held in Cambridge, 29th July 2015

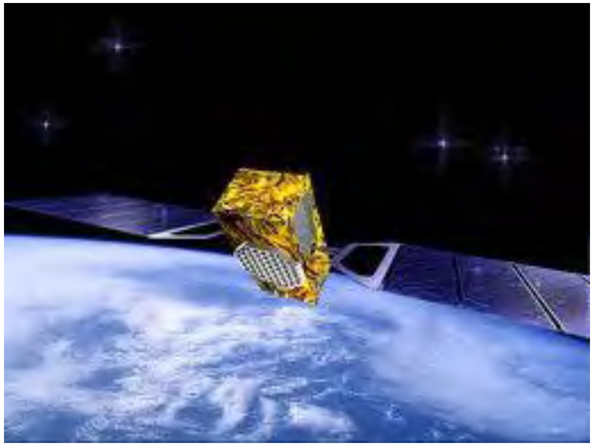
<u>Subject Matter Experts</u>

- British Antarctic Survey
  - Dr Richard Horne
- Cambridge Department of Applied mathematics and Theoretical Physics
  - Dr Helen Mason
- British Geological Survey
  - Dr Alan Thomson
- University of Cape Town
  - Professor Emeritus C. Trevor Gaunt
- Plus other representatives from electric utilities, government and regulators

Overview of CRS Solar Storm Scenario



- Scientist detect a large active solar storm sunspot
- Relatively moderate CME and flare emitted:
  - CME speed = ~450km/s ± 500km/s
  - Flare size (M5) = < $5x10^{-5}$ W/m^2
  - NOAA estimates a G2 category geomagnetic storm in four days' time
- Three days later, a large build up of energy due to an efficient magnetic reconnection process, leads to a giant high-mass CME being discharged towards Earth:
  - CME speed = ~2000km/s ± 500km/s
  - Flare size (X20) = $2x10^{-3}$ W/m^2
  - Solar radiation storm = 10^4 MeV

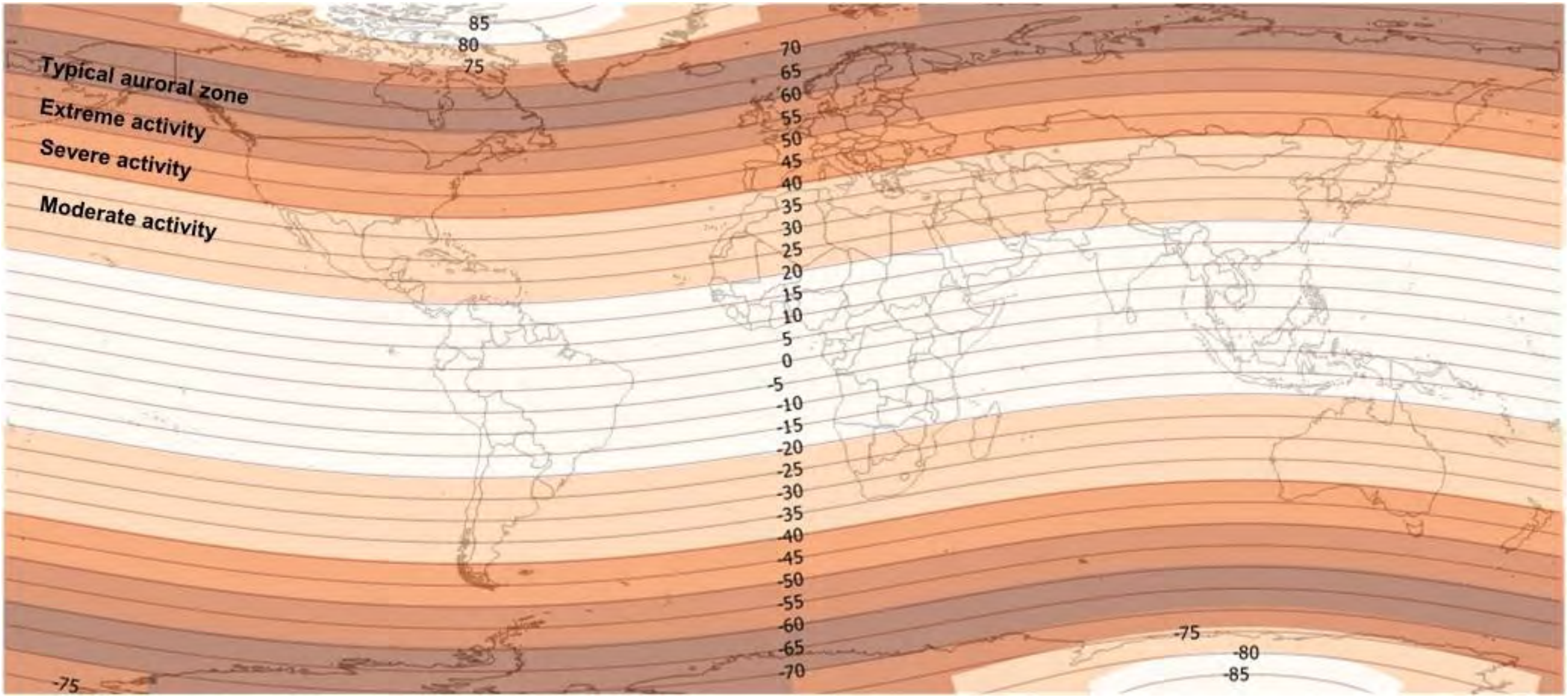


- Satellite systems provide 60 minutes warning of incoming CME:
  - Bombards Earth's magnetosphere, forcing a reconfiguration between the southward-directed interplanetary magnetic field and Earth's geomagnetic field
- The second CME reaches Earth in only 20 hours:
  - Consequently billions of tonnes of gas containing charged particles intensify the shock compression
  - Particles are accelerated along the magnetotail, back towards Earth being deposited in the auroral ionosphere and magnetosphere on the night side of the Earth, directly above North America
  - Dst measurements = ~ -1000nT
  - dB/dt measurements = ~5000nT/m at 50° magentic latitude

- Auroral oval forced equatorward by 15° magnetic latitude
- Numerous substorms
  - Take place every few hours on the dawn-to-dusk side of the Earth due to the highly dynamic nature of the auroral electrojet roughly 100km above ground
- Geomagentic effects
  - Rapid change in the magnetic field rate-of-change down to 50° magnetic latitude
  - Ring current intensifications take place down to 20° magnetic latitude
  - Minor and major damage to EHV transformers

CME = coronal mass ejection

Cambridge Global Geomagnetic Storm Threat Map

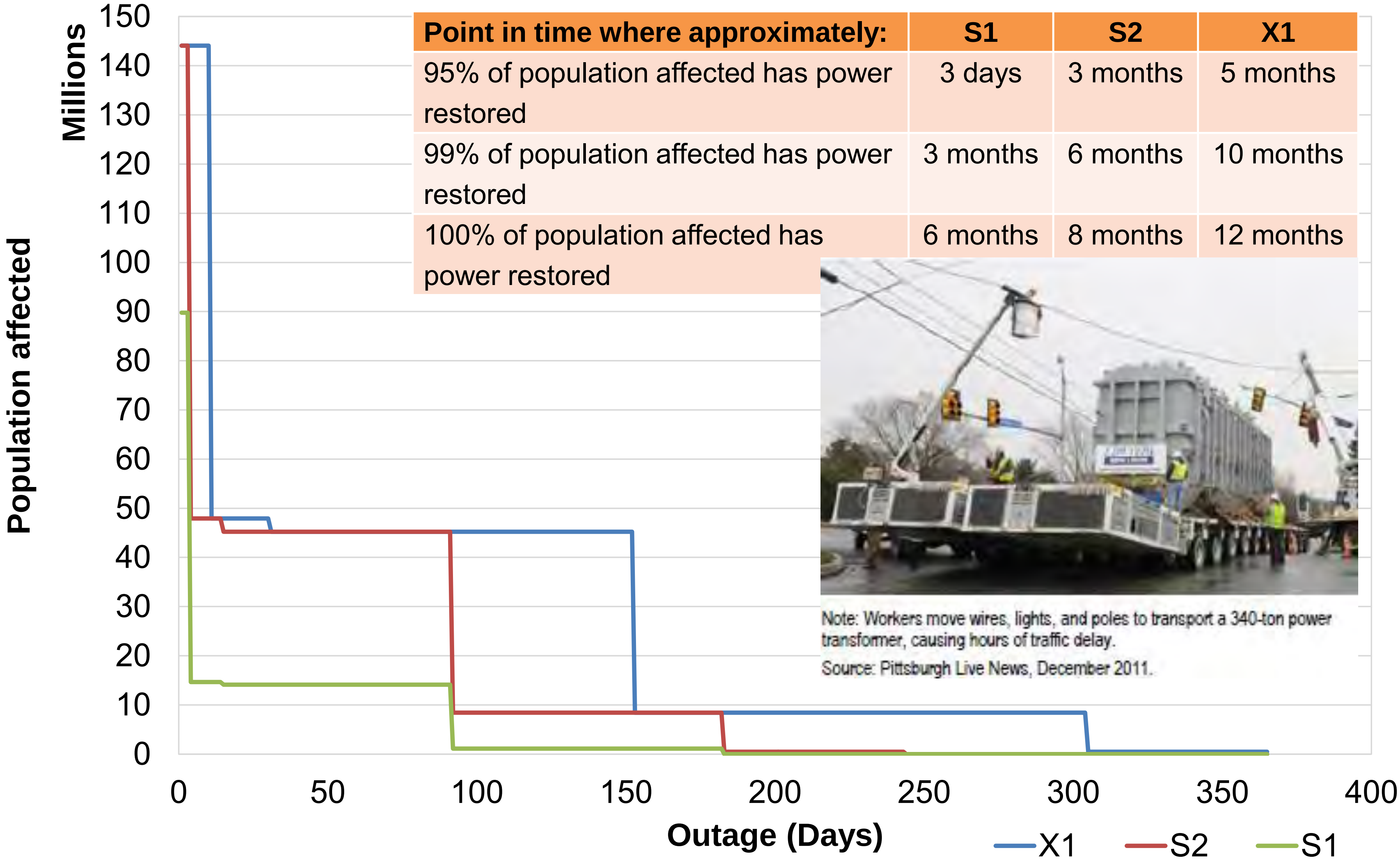


- Exposure based on geomagnetic latitude lines
- 38% of the world population is less likely to be exposed to the storm

Notes: The contour lines on this map were generated using the World Magnetic Model (WMM) 2015 shape file from NOAA (Chulliat, 2014).

US Restoration Curves

Point in time where approximately:	S1	S2	X1
95% of population affected has power restored	3 days	3 months	5 months
99% of population affected has power restored	3 months	6 months	10 months
100% of population affected has power restored	6 months	8 months	12 months



Note: Workers move wires, lights, and poles to transport a 340-ton power transformer, causing hours of traffic delay.

Source: Pittsburgh Live News, December 2011.

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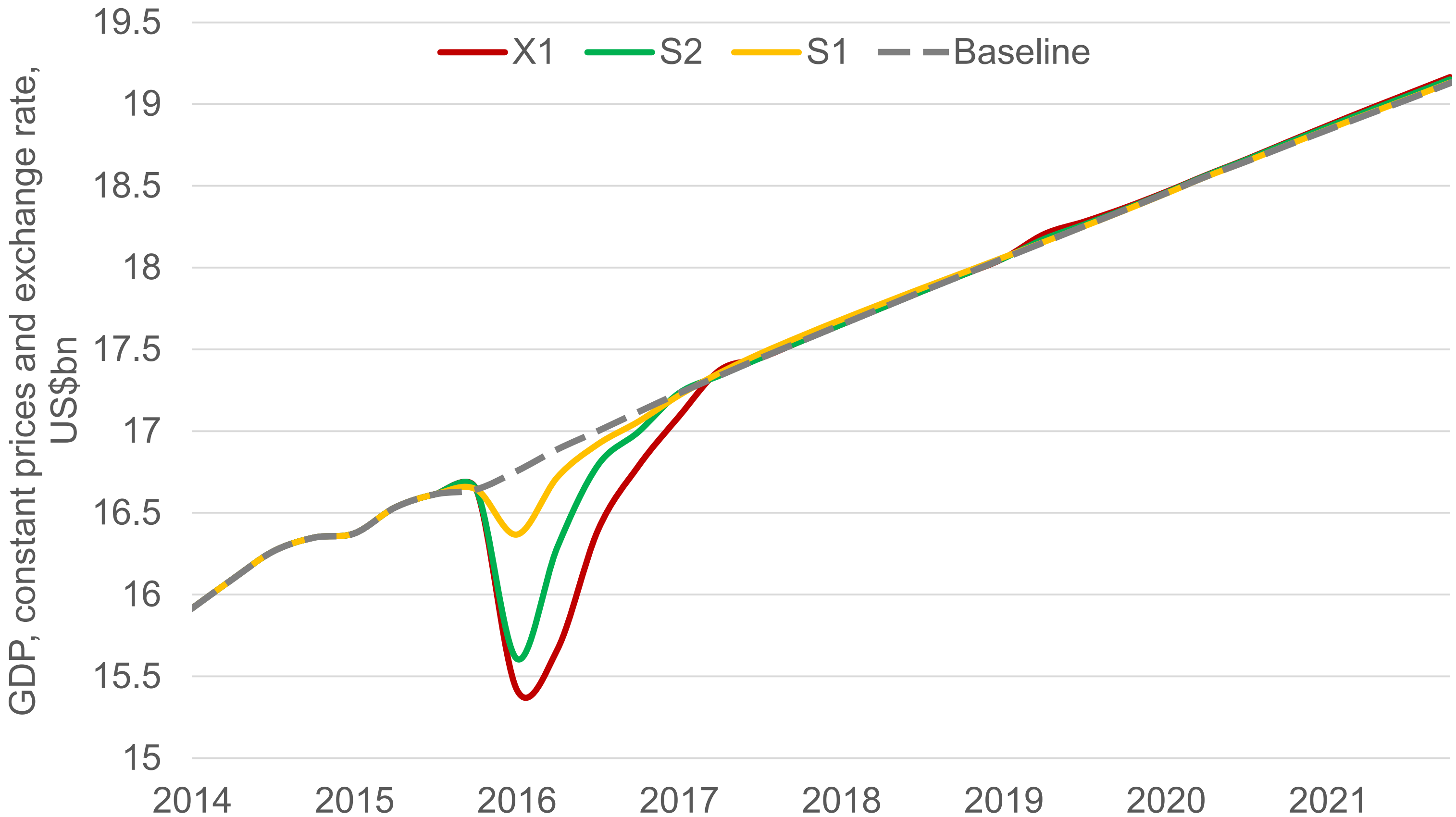
Macroeconomic Modelling



Scenario Variants	5-year Global GDP@Risk, US$ Bn (From OEM analysis)
S1	$136 (0.2%)
S2	$319 (0.4%)
X1	$613 (0.7%)

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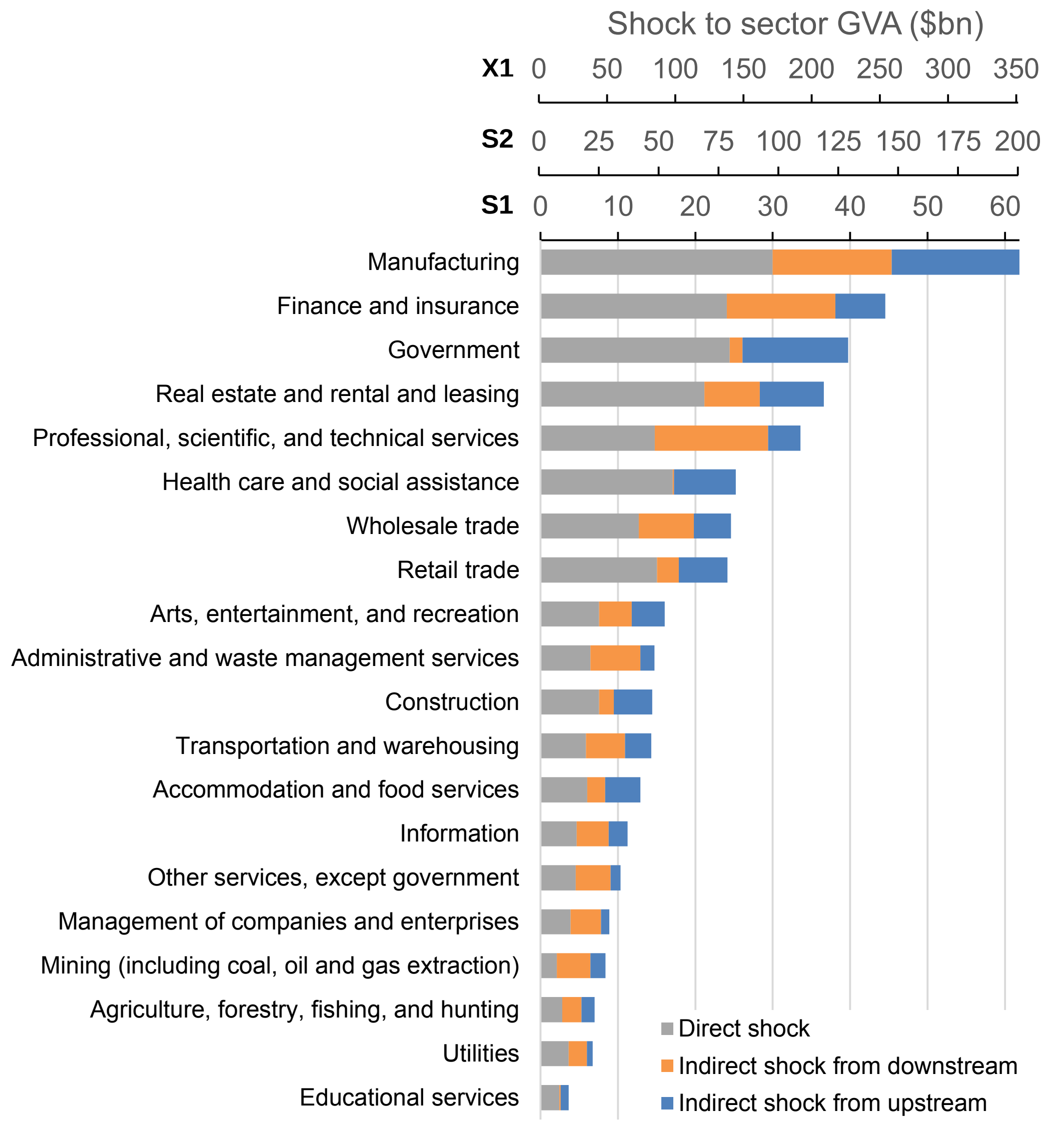
Direct and Indirect Shock by Sectors



Scenario Variant	Total Direct and Indirect shock, US only, $Bn
S1	$474
S2	$1,532
X1	$2,693

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US Insurance Loss Estimate

	Claimant Type	Coverage	$ millions
1	Power Transmission Companies	Property Damage (EHV transformers)	466
		Incident Response Costs	29
		Fines – FERC/NERC	4
		Directors and Officers Liability	600
	Power Generation Companies	Property Damage (generator step-up transformers)	84
		Business Interruption	423
		Incident Response Costs	4
		Fines – FERC/NERC	4
		Directors and Officers Liability	95
2	Companies that loss power	Perishable contents	1,079
		Contingent business interruption – service interruption/utility interruption/suppliers extension	50,983
3	Satellite	Property damage (satellites)	218
	Homeowners	Household contents	449
	Speciality	Event cancellation	603
		Total	55,040

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For variant S1, $ millions

1 Power Transmission Companies

- Property Damage (EHV transformers)

Damage Scale	Damage Scale Description	% of transformers			Damage factor
		S1	S2	X1	
D0	Not Affected	68%	49%	49%	0%
D1	Tripped Off	26%	33%	33%	0%
D2	Minor Damage	5%	14%	14%	30%
D3	Major Damage	0%	3%	3%	100%
D4	Destroyed	0%	0.2%	0.2%	100%

– Assumed that **100%** have Property Damage insurance
– Assumed average cost of installed EHV transformer, **$11.25 million** (DOE, 2014)
– Deductible: **$0.5 million**
– Limit: **$11 million**
– Total: **$466 million of payouts**

Typical EHV transformers:

- EHV = extra high voltage
- EHV transformers are defined as 345 kV and greater
- They are used to convey power long distances
- There are ~ 2,300 EHV transformers in the US
- They are vulnerable during a solar storm due to increased GICs

The scenario would affect around 7% of EHV transformers in the US in S1 variant, resulting in property damage and BI claims

2 Companies That Lose Power

- We use a data set from the US Census Bureau (2016) for number of establishments and revenue by NAICS sector by US state
  - There are **1.1 million** large facilities (500+ employees) in the US
- Policy holders claim the outage is the result of fire at the generators/transformer - a standard FLEXA peril
- Contingent business interruption – service interruption/utility interruption/suppliers extension
  - We estimate ~ **222,000** large facilities or **19%** (500+ have Suppliers Extension insurance
  - A dataset from Energy Information Administration, 2015 provides an estimate for the number of companies with backup generators by sector
  - Use the US state restoration curves to determine the percent of companies that experience a loss of power longer than contractual retentions
  - Deductible: **24 hours**
  - Sublimit: **$15 million**
  - Total: **$50,983 million of payouts**
- Perishable contents are spoiled during the outage and also cause a insurance claim

Typical US Facilities with back-up generators:

- Manufacturing
- Utilities
- Mining, Quarrying, and Oil and Gas Extraction
- Educational Services
- Health Care and Social Assistance

Backup generators, if working properly could prevent loss of perishable contents

3

Satellite Owners

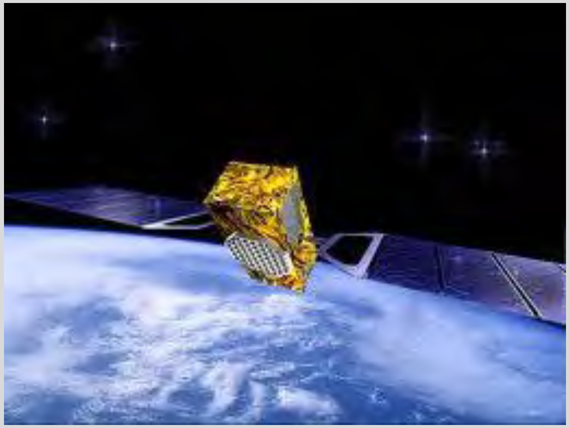
- Satellite loss

Satellite Type	Purpose	Typical Users	Insured
Low Earth Orbit (LEO)	Imaging, Earth observation, data services	Commercial	Insured
Mid Earth Orbit (MEO)	GPS, Military	Government	Typically not insured
Geostationary (GEO)	Communications, TV, Broadband	Commercial	Insured

- Using the 'best engineering estimate' from the RAE 2013 report, we estimate that **18** satellites (GEO and LEO only) are damaged in the S1 scenario variant
  - Permanent loss of functionality, machinery breakdown
- Assumed asset values (from Swiss Re Report, 2011):
  - LEO: **$75 million**
  - GEO: **$150 million**
- We also assume on 20% damage factor
  - Deductible: **no deductible**
  - Limit: **no limit**
  - Total: **$218 million of payouts**

Typical Satellites:

- There are over 1,200 operational satellites in space as of year-end 2014 (SIA, 2015)
  - There are ~ 456 active satellites around Earth that are for commercial purposes only (38%)
- Of these about half are owned by US companies
- Based on a Swiss Re report, we estimate that about 12% of LEO and 56% of Geo satellites are insured, globally



It is estimated that this scenario will impacted 10% of satellites

Insurance Industry Loss Estimates for Solar Storm Scenario

Scenario Variant	Outage Duration	Total Direct and Indirect, US only, $ Bn	US Insurance Industry Loss Estimate, $ Bn	Insurance Loss as a % of economic loss
S1	6 months	$474	$55	12%
S2	8 months	$1,532	$173	11%
X1	12 months	$2,693	$334	12%

For context:

- Total insurance catastrophe losses 2015: $85 Bn
- Hurricane Katrina 2005: $80 Bn
- Tohoku Earthquake Japan 2011: $38 Bn
- Superstorm Sandy 2012: $37 Bn
- Hurricane Andrew 1992: $28 Bn
- 9/11 WTC 2001: $26 Bn

[2015 $ value]

Areas Not Estimated Where Losses Could Occur

- Transformer manufacturers
- Telecommunications and GPS/GNSS failure
- Rail transportation
- Goods in transit
- Auto
- Aviation
- Travel
- Industrial accidents/environmental liability

Mitigation Plans

- Operational mitigation
  - Relies on early notification systems
  - Increase spinning reserve and reactive power
  - Reduce/remove the load on key transformers
  - Unlikely that equipment will be turned off
- Engineering mitigations
  - Hardening the transmission equipment to prevent GICs from flowing through it, more resistive transformers
    - Requires expensive capital improvements/replacements
- Progress by geography
  - UK: replacing about 10 transformers per year, currently have 50% more resistive
  - US: NERC is still in review period of the engineering/thermal assessments requirement
  - Australia: has recently done solar storm studies of its electricity system
  - Nordic Countries: well prepared
  - Japan: just starting to look into engineering improvements, but very concerned of the threat
  - China: just took first geomagnetic measurements this year
- Improving solar storm forecasting and upgrading solar storm early warning/alert systems
- Use smarter grid technologies to improve situational awareness such as automatic voltage stabilisation and other automatic protective measures
- Coordinated policy action

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